Combined Task and Physical Demands Analyses towards a Comprehensive Human Work Model

Philip S. E. Farrell, Ph.D.
Defence R&D Canada, 1133 Sheppard Avenue West, Toronto, ON, Canada, M2R 3B4

David W. Tack, M.Sc., CHFP
Edward T. Nakaza, M.Sc., CCPE
Jordan Bray-Miners, M.A.Sc
Human*Systems*® Incorporated, 111 Farquhar Street, Guelph, ON

Cristopher M. Farrell, B.A.

Task analyses and physical demands analyses are combined to identify common and extreme postures and postural sequences, durations, frequency, and forces for Griffon Helicopter aircrew tasks, mission phases, and whole missions. The result is a comprehensive model of tasks and associated physical demands from which one can estimate the accumulative neck loads and moments caused by Night Vision Googles usage. Combining task and physical demands analyses yields a methodology for building a model of human work where information processing and physical demands are equally important for finding effective solutions to work issues.

INTRODUCTION

Griffon Helicopter aircrew (Pilots and Flight Engineers) reported neck pain particularly when wearing Night Vision Goggles (NVGs) (Forde et al., 2011; Neary, Salmon, Harrison, & Albert, 2010). 162 out of 290 (56%) Griffon aircrew reported pain of which 37 were officially grounded and 41 grounded themselves due to the severity of the pain (Chafe et al., draft). Finding a solution to this problem is a high priority for the Canadian Armed Forces, other international forces (NATO, 2013), as well as aircrew who suffer through neck trouble during their missions.

Defence Research and Development Canada has launched a neck- and back-trouble research program that assesses the extent to which proposed solutions mitigate these concerns. The solutions include new integrated low profile light weight helmet systems, helmet support devices, neck strengthening, helmet fit protocols and education, and new or modified tasks and postures. The research involves the development of an instrumented test bed facility to test and evaluate potential solutions as well as generate head supported mass (HSM) properties requirements by systematically varying mass and center of mass on the head and correlating these properties to neck trouble (injury, discomfort, strain pain, etc.). A front end analysis, which involves task and physical demands analysis, is required specifically for developing new tactics, techniques, and procedures (TTPs), a pre-assessment of solutions using modelling and simulation, and producing experimental protocols and composite scenarios for the test bed facility and HSM study.

While task analyses highlight the activities that aircrew perform, physical demands analyses characterize the exposure (intensity, duration, and frequency) of forces and moments on the body for each task. The challenge of this front end analysis is to characterize neck forces and moments noninvasively not only for a few simple tasks but for all tasks over the mission duration and for all crew positions: flying pilot (FP), non-flying pilot (NFP), and flight engineer (FE).

Instead of performing two separate analyses, this paper exploits overlaps between task and physical demands analyses and proposes a single combined analysis. The next section provides a brief synopsis of each analysis and highlights the overlap. This is followed by a description of the proposed combined approach. The fifth section gives an example of the approach's outcomes. The paper concludes with a way ahead for the neck strain study.

TASK ANALYSIS TECHNIQUES

Task analysis theory suggests that human work can be systematically decomposed and represented as an abstraction hierarchy of functions and tasks. Once decomposed, visual, audio, cognitive (information), and psychomotor (Wickens, 2008) and physical requirements can be associated with each task, and time pressure and workload can be estimated across task sequences (Hendy, Liao, & Milgram, 1997). Mission Function Task Analysis (MFTA) as described in (DOD, 1999; Miller, 1953) represents a traditional hierarchical task analysis. MFTA is ideal for procedural work where

mission objectives are well known a priori (e.g., slung-load training) and can be readily decomposed into mission functions (e.g., takeoff, transit, hook-up, transit, drop-off, transit, and land). Functions can be further decomposed into sub-functions until they can be allocated to either the machine (e.g., generate lift) or the human operator (e.g., manipulate collective and scan out-the-window for obstacles). Once allocated to the operator, functions become tasks, which are further decomposed into sub-tasks (e.g., move eyes, head, torso, and hands). Postures can be represented by body links and joint angles. These joint angles are achieved by activating muscles (still subtasks in the task hierarchy) that exert forces and moments on neck joints along with any head-borne mass. These low level tasks clearly overlap with the information garnered from a traditional physical demands analysis.

There are many variants to a traditional MFTA including Cognitive Task Analysis (Klein, 1995) that focuses on describing cognitive tasks such as perceiving, accessing working memory, and decision-making. Hierarchical Goal Analysis (Hendy, Beevis, Lichacz, & Edwards, 2002) decomposes human work into a hierarchy of perceptual goals and examines the perceptions and actions needed for goal achievement. Cognitive Work Analysis (Vicente, 1999) emphasizes work domain function decomposition although it involves task decision ladders as a latter analysis step. Perceptual control theory Analysis Technique (Farrell & Chéry, 1998) ambitiously attempts to decompose behavioral tasks, cognitive tasks, perceptual goals, and work domain functions all within the same feedback control framework. These methods have in common a hierarchical description of human work usually starting at high abstraction levels of the work's purpose down to the level of physical action (Farrell & Ho, 2000). Clearly, MFTA overlaps with physical demands analyses at the lower levels.

PHYSICAL DEMANDS ANALYSIS TECHNIQUES

Physical Demands Analysis (PDA) is a means of capturing mechanical forces and stresses that a job imposes on a worker or a worker applies to their work environment. It is also used to determine job compatibility (Couture & Richings, 1998) and physical requirements for a worker to complete the job safely (Myers, Gebhardt, Crump, & Fleishman, 1984), whether the job already exists or is being created. A PDA is often used for injury investigation in the workplace so that health care specialists, managers, insurance companies, and governments can take action or make policy to prevent injury by introducing new equipment

or modifying tasks and providing training (van der Molen, Sluiter, Hulshof, Vink, & Frings-Dresen, 2005).

List the Job Duties
(the main functions or different parts of the job, e.g., "sweep; collect garbage; clean glass")

Duty #	
Duty Name	
How often is this duty performed *(e.g., once a day, 5 times per hour)*	How long is the duty performed each time it is done? *(e.g., 1 min., 2 hrs)*

Figure 1: PDIF Duties excerpts

A typical PDA requires the completion of a form that asks certain questions of the worker and manager. For example, the Workplace Safety & Insurance Board (WSIB) of Ontario has a Physical Demands Information Form (PDIF) that ask questions regarding the neck, shoulder, back, elbow, forearm, wrist, hand, hip, leg, knee, ankle, and foot for job duties (i.e., tasks) and their frequency and duration (WSIB & CSPAAT, 2014) as shown in Figure 1. The PDIF also solicits posture, frequency (Figure 2), and force categorical data (Figure 3) for each duty. Thus, some form of task analysis or description is associated with PDA, albeit not as formal as described in the previous section.

Neck Postures / Movements:
What are the positions of the neck?
☐ Straight (i.e. neutral)
☐ Bent (check appropriate)
☐ Forward ☐ Back ☐ to the side
☐ Turned (check appropriate)
☐ Left ☐ Right
How often does the neck move?
☐ _____ times per hour OR
☐ Not at all (stays in the same position)
☐ Occasionally (no regular motion)
☐ Frequently (regular motion with pauses)
☐ Constantly (continuous motion)

Figure 2: PDIF Posture and Frequency Excerpts

Some PDA efforts use motion capture systems and load cells to collect joint angles and forces and moments, respectively (Jones, Reed, & Chaffin, 2013). Such studies often focus on very specific phases of a job where, for example, significant health and safety concerns have arisen and objective validation (baseline versus treatment) is required to assess whether new kit,

policies, or procedures mitigates the problem. For the aircrew neck strain study, it is believed that cumulative load exposure over the mission (or missions) is significantly higher during night than day operations due to NVG usage, and a PDA with objective data collection may be employed to quantify this load exposure. These objective methods combined with a formal task analysis may allow us to estimate cumulative loads for not only one specific phase of the job, but for the entire mission or over the course of several missions.

Force Exerted:	
Which of these actions are performed?	*Indicate weight or effort (e.g. light, medium, heavy)?*
☐ Lifting:	_____
☐ Lowering:	_____
☐ Holding:	_____
☐ Carrying:	_____
☐ Pushing:	_____
☐ Pulling:	_____

Figure 3: PDIF Force Excerpts

COMBINED ANALYSIS APPROACH

This section presents the initial concept for the combined analysis approach, a synopsis of the application of the approach to the Griffon Helicopter aircrew neck strain problem, and the refined concept of the approach as a result of lessons learned from the application.

The initial concept is formulated by first recognizing the overlaps between task and physical demands analyses: task analyses extend down to the level of physical activities where physical demands can be linked to these activities, and a PDA incorporates some form of task description albeit quite informal.
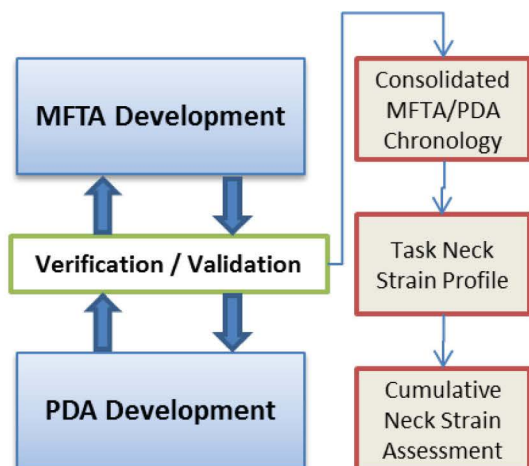

Figure 4: Combined Analysis Approach

Figure 4 depicts a combined approach to task and physical demands analyses, which ultimately has the potential to yield a cumulative neck load or "neck strain" profile. The approach begins with a traditional MFTA development where data collectors would interview Subject Matter Experts (SMEs) and walk them through a series of scenarios, missions, functions, and tasks in order to build a task hierarchy and task sequences that represent human work. Verification and Validation of the MFTA portion may be performed with video data of humans working in their environment or soliciting additional opinions from other SMEs.

Once the lowest level tasks are identified and verified, SMEs are asked to identify the postural sequences associated with each task. The Verification and Validation of the postural sequences can be done with video or motion capture systems (SMEs can also be used, motion capture yields objective data). The result of these two combined analyses is a relational database that links the mission to functions to tasks to postural sequences, with which any number of analyses can be performed including an assessment of neck strain.
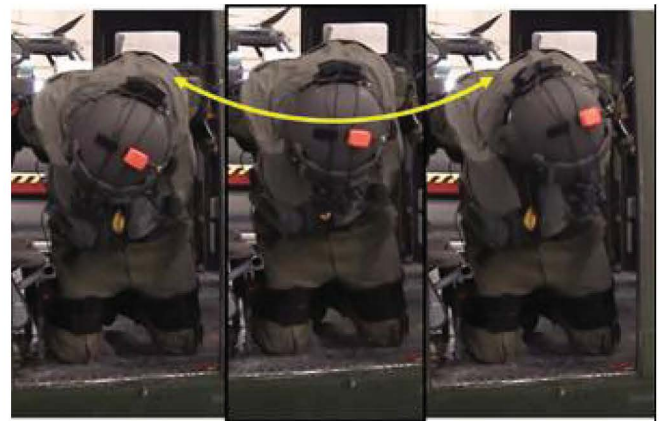

Figure 5: "Scan slung load" postural sequence showing 1 Flight Engineer (FE) with NVGs at 3 time intervals. Orange motion capture sensor mounted on helmet is one of 7 motion capture sensors.

This initial combined approach concept was applied to the neck strain issue. The mission, task content and currency, and task and activity flows of the existing Griffon Helicopter task hierarchy (McKay, MacDougall, & MacDonald, 1997) were reviewed with pilot/FE SME pairs, and updated to 2014 tactics/techniques/procedures and reconstructed into a new Mission Task Libary. The SMEs identified common postural sequences (Figure 5) typically associated with standard mission tasks (12 for pilot flying, 12 for non-pilot flying, and 26 for FEs). These postural sequences were demonstrated, described, and catalogued. A single postural sequence was often

associated with many different mission tasks (e.g. "Scan slung load" was associated with nine discrete mission tasks). The SMEs associated postural sequences with tasks, for all three aircrew roles, their duration, and the percent of time spent in each postural sequence associated with each task (figure 6).

Mission Task	Dur. (sec)	FP Post 1	FP Post 1 (%)	NFP Post 1	NFP Post 1 (%)	FE Post 1	FE Post 1 (%)
Take-off with Slung Load	60	Outside Scan Regular	100	Outside Scan Regular	50	Scan Slung Load	100

Figure 6: "Take-off with slung load" mission task decomposed into postural sequences for FP, NFP, FE

Finally, pilots (in their flying and non-flying roles) and FE's simulated each of the common postural sequences identified for each MFTA mission, using motion capture methods to capture joint position, joint angles, velocities, and accelerations over time for each postural sequence. Neck strain measures derived from biomechanical analyses of these postural sequences were then populated back into task flows for all three aircrew roles over the entire duration of each mission type.

DISCUSSION

The combined approach to task and physical demands analysis results in a more comprehensive model of human work within their work environment. The model includes missions represented by a task hierarchy where each low level task is linked to postures (or a postural sequence), as well as frequency, duration, and loads associated with each sequence. Using this approach, the pattern and profile of various neck strain measures can be tracked over time to identify peak and cumulative neck strain exposure over the course of one or several missions (including training), which is a limitation of current research methodologies.

In terms of the impact of this database on new TTPs, it was observed that the task, "Scan slung load" requires a FE to kneel and lean out of the helicopter side door and continually check for obstructions for the slung load that is dangling from the helicopter. (Not all FEs adopted this posture, thus there were individual differences in performing postural sequences). In operations this task takes about 20 minutes and crews can normally perform this task without reports of neck pain, even though the physical demands are quite high in a single event (figure 7).

However, during the basic FE course, the student must repeat this manoeuvre many times, and moreover the instructor must lean over the student in a very awkward position and observe both student and slung

load. Anecdotally, FEs have indicated that this training alone has the potential to ground them especially with the use of NVGs (figure 8).
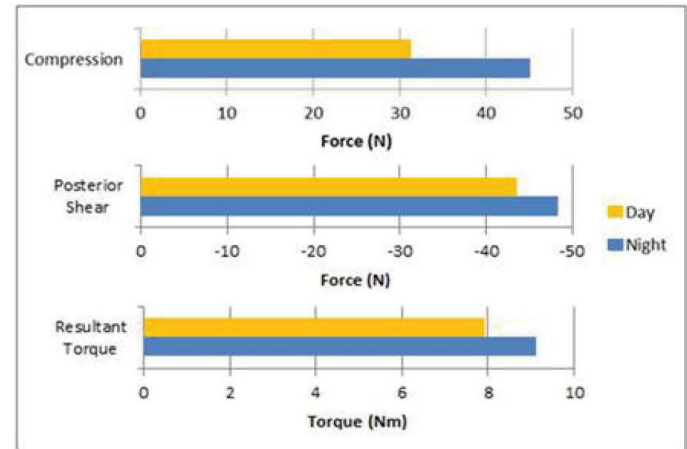

Figure 7: FE Neck forces and moments for "Scan slung load" postural sequence (with and without NVG)
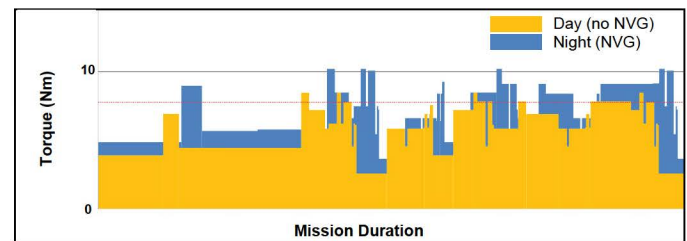

Figure 8: FE resultant neck torque – slung load training mission (with and without NVG)

A potential new TTP would be to perform some fraction of "Scan slung load" training in a task part trainer with all the proper visual cues but none of the additional neck loads. Once the trainer feels that the student is proficient in the trainer, then fewer runs would need to be performed in the field.

In terms of using the model to help develop a testing facility, the original plan was to incorporate the composite scenario into a high fidelity simulator and then ask crews to "fly" the proposed solution. However, since the combined approach yielded a finite set of postural sequences, related to all tasks in the composite scenario), the test bed need only be set up to test the 50 postural sequences. Then the cumulative load estimation can be used to determine the efficacy of a proposed solution compared to the current Helmet/NVG system. This strategy could significantly reduce test and evaluation costs.

In terms of the HSM study, neck joint angles calculated throughout the mission using the new human work model would allow for each subject to assume 3 or 4 angular positions around the x-, y-, and z-axes. And so, it would not be necessary to have subjects perform all 50 postures thus saving a significant amount of time.

In the future we hope to relate electromyography (EMG) data collected at the neck and link them to each postural sequence. EMG would provide insight into muscle activation levels for each task with and without the NVGs and the ability to optimize for cumulative neck loading based on fatigue curves to limit exposure (i.e. refine work-rest schedules).

CONCLUSIONS

A robust approach was conceived and implemented that combines task and physical demands analyses. The result is a comprehensive model of human work that incorporates elements of human information processing, physical loads, and workplace constraints and affordances. The CAF will use the human work model for multiple purposes including deriving new TTPs for mitigating neck strain, test and evaluating proposed solutions, conducting HSM studies for the Griffon helicopter and other airframes, and investigating interface midlife upgrades and ergonomic seat design.

The next steps are to incorporate motion capture data into the digital human model to conduct further parametric studies evaluating proposed helmet designs, evaluate midlife upgrades of the instrument panel and ergonomic designs for pilot and FE chairs estimating periods of high physical demand, as well as cumulative loading across each postural sequence, task, and mission.

REFERENCES

Chafe, G., Farrell, P. S. E., Hendricks, T., Hollands, J., Jones, M. L. H., & Sy, A. (draft). *CH-146 Griffon aircrew 2014 musculoskeletal trouble survey*. Technical Report, DRDC TR 2014-xxx, Defence Research and Development Canada, Toronto, ON.

Couture, C., & Richings, J. (1998). Physical Demands Analysis "The Cornerstone of any Return to Work Program". Retrieved from http://sibley.ca/wp-content/uploads/2011/04/Physical-Demands-Analysis-The-Cornerstone-of-an.pdf on 22 February, 2014 website:

DOD. (1999). *Human Engineering Program Process and Procedures*. (MIL-HDBK-46855A). Department of Defense Retrieved from http://quanterion.com.

Farrell, P. S. E., & Chéry, S. (1998). *PAT: Perceptual control theory Analysis Technique*. Paper presented at the Human Factors and Ergonomics Society, Chicago.

Farrell, P. S. E., & Ho, G. (2000). *Exploring Work Domain Analysis Techniques*. Paper presented at the IEA Triennial Meeting/Human Factors and Ergonomics Society 44th Annual Meeting, San Diego.

Forde, K. A., Albert, W. J., Harrison, M. F., Neary, J. P., Croll, J., & Callaghan, J. P. (2011). Neck loads and posture exposure of helicopter pilots during simulated day and night flights. *International Journal of Industrial Ergonomics, 41*(2011), 128-135.

Hendy, K. C., Beevis, D., Lichacz, F., & Edwards, J. L. (2002). Analysing the cognitive system for a perceptual control theory point of view. In M. D. McNeese & M. A. Vidulich (Eds.), *Cognitive systems engineering in military aviation environments: Avoiding cogminutia fragmentosa!* (pp. 201-252). Dayton, Ohio: Wright-Patterson Air Force Base, OH: Human Systems Information Analysis Centre.

Hendy, K. C., Liao, J., & Milgram, P. (1997). Combining time and intensity effects in assessing operator information-processing load. *Human Factors, 39*, 30-47.

Jones, M. L. H., Reed, M. P., & Chaffin, D. B. (2013). The effect of bracing availability on one-hand isometric force exertion capability. *Ergonomics, 56:4*, 667-681. doi: 10.1080/00140139.2013.765601

Klein, G. (1995). *The Value Added by Cognitive Task Analysis*. Paper presented at the Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting, San Diego, California.

McKay, D. E., MacDougall, D. A., & MacDonald, G. S. (1997). Human Factors Engineering Study for a Griffon Mission Planning System (pp. 372). Ottawa, Canada: DCIEM No. 97-CR-19 Defence Research and Development Canada.

Miller, R. B. (1953). A Method for Man-Machine Task Analysis: WADC Technical Report 53-137, Wright Air Development Center Air Research and Development Command, Wright-Patterson Air Force Base, Ohio.

Myers, D. C., Gebhardt, D. L., Crump, C. E., & Fleishman, E. A. (1984). Validation of the Military Entrance Physical Strength Capacity Test (pp. 188): Technical Report 610, U.S. Army Research Institute for the Behavioral and Social Sciences.

NATO. (2013). Aircrew Neck Pain. Technical Activity Description HFM 252: Paris, France.

Neary, J. P., Salmon, D. M., Harrison, M. F., & Albert, W. J. (2010). Pain and Disability in Military Helicopter Aircrew: The Efficacy of Exercise Training Programs in Reducing Neck Pain and Fatigue in Canadian Forces Helicopter Aircrew (pp. 64). Toronto, Canada: Research funded by Canadian Forces Quality of Life Grant #1725981 & Military Health Program #W3931-050513-001/SV, Defence Research and Development Canada.

van der Molen, H. F., Sluiter, J. K., Hulshof, C. T. J., Vink, P., & Frings-Dresen, M. H. W. (2005). Effectiveness of measures and implementation strategies in reducing physical work demands due to manual handling at work. *Scandinavian Journal of Work, Environment and Health, 2005;31, suppl 2:75-87.*

Vicente, K. J. (1999). *Cognitive Work Analysis Toward Safe, Productive, and Healthy Computer-Based Work*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Wickens, C. D. (2008). Multiple Resources and Mental Workload. *Human Factors, 50*(3), 449-455.

WSIB, & CSPAAT. (2014). Physical Demands Information Form. Retrieved from http://www.wsib.on.ca/files/Content/Downloadable%20FilePDIF/PDIF.pdf on 22 February, 2014 website: